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E. R. JACOBS, W. H. SMITH AND A. W. VINSON.

AN INVESTIGATION INTO THE BREAKING DOWN POINTS FOR PERFECT LUBRICATION UNDER VARYING SPEEDS, PRESSURES AND TEMPERATURES.

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An Investigation into the Breaking Down Points for Perfect Lubrication under Varying Speeds Pressures and Temperatures

By

Ernest R Jacobs
William Hooper Smith
Albert Wilkinson Vinson

A Thesis Submitted for the Degree of
Bachelor of Science
Mechanical Engineering Course

UNIVERSITY OF WISCONSIN
1905

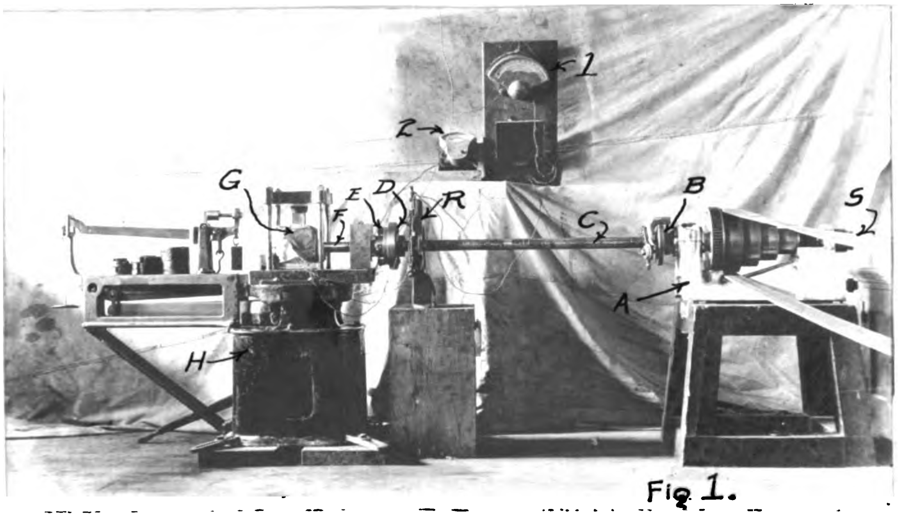
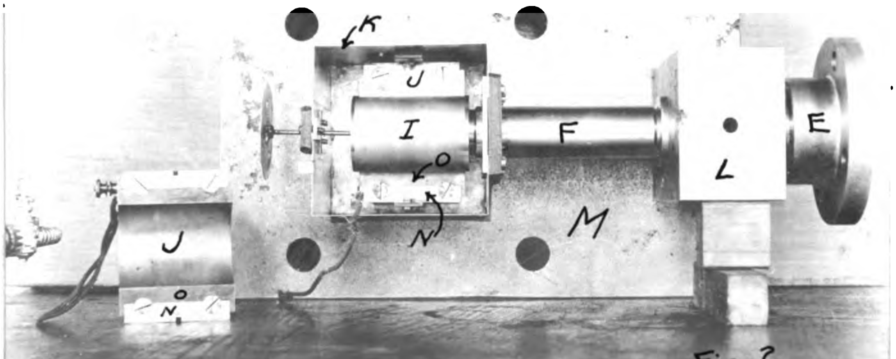


Fig. 1.



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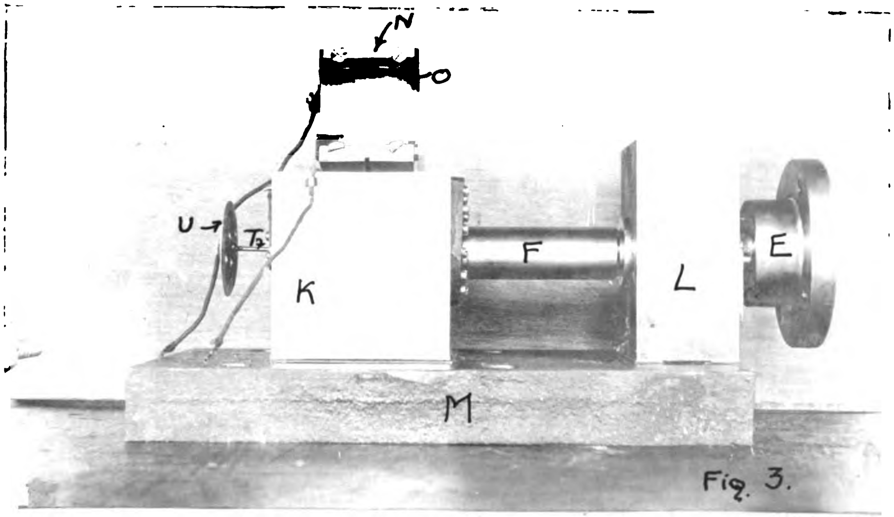

Fig. 3.

OUTLINE.

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CHAPTER I.

Introduction:-- Friction, "the highway robber of mechanical energy", as it is often aptly termed, has of late been the subject of much experimental research. Until recent years very little was known about the friction of bearings, but recently extensive tests have been made which have thrown considerable light on this subject, and have given us some very exact information. At the present day there are no journal bearings made which it is certain will not run hot sooner or later in the course of their operation and many of the experiments performed in this connection have been made in the hope of gaining some alleviation of this trouble. Designers have been made to realize that journal friction is one of the most important points in machine construction.

Properties of Oils:-- The two important porperties of lubricating oils and greases, on which their value depends are "viscosity" and "body". "Viscosity" is that property by virtue of which the lubricants form comparatively thick films between rubbing surfaces, permitting what is called perfect lubrication, which from the work of Tower, Reynolds and Thurston has been found to be capable of exact mathematical treatment. The "body" of the oil is more difficult to define but it is generally known as the "oiliness" of the lub-

ricant. When the body is effective on the bearing instead of the viscosity, perfect lubrication is impossible. As the tests of which this thesis is descriptive were made under the conditions of perfect lubrication the viscosity of the oil is the only property of interest.

Purpose of Tests:-- The objects of series of the tests about to be described may be briefly given as follows:

> "To show precisely what are the effects upon perfectly lubricated surfaces, of simple variation of speed and simple variation of pressure, unaccompanied by variation of the conditions of the metal surfaces between which the lubricants are placed."

It is natural to presume that the variation of speed and pressure will cause some change in the temperature of the oil, and therefore in the viscosity of the same; and the results obtained proved this to be the case. Hence the temperatures have been taken into account in plotting data and drawing conclusions.

Perfect lubrication and tests with imperfect lubrication: What are the conditions for perfect lubrication? Quoting Professor Albert Kingsbury there must be, (Vol. XXIII, A. S. M. E.), "a complete separation of the metals, maintaining the film of oil intact throughout". In earlier experiments there has always been more or less metallic contact, intro-

ducing a change in the law of variation. The results of all such tests have been very carefully treated by Professor R. H. Thurston. The work done heretofore has been the determination of,

1. The change of viscosity with temperature.
2. Normal temperature under varying pressures.
3. Friction coefficient at varying pressures.

There are no tests to be found showing at all completely the relations which the following results are intended to establish. All the work which has been done on this subject has gone to prove that economy in the use of lubricants can be obtained,not by saving costs in purchasing oils, but by saving power by the use of good oils.

Formation and destruction of film:- For the formation of the film so essential to perfect lubrication the rubbing surfaces must have a slight inclination to each other in the direction opposite to their relative motion.In following experment this is obtained by a difference between the diameters of journal and bearing of three thousandths of an inch, (.003"). When the load becomes so great as to materially reduce this 0.003" space between journal and bearing, perfect lubrication is destroyed and imperfect lubrication is set up, as the oil will never cease entirely to act in reducing friction. With imperfect lubrication, however, the

friction reducing value of the oil depends on its body or "oiliness". This oiliness appears to be "an intensified viscosity in that part of the fluid within the region of attraction of the surface molecules of the metal". (Kingsbury.)

Factors considered in tests:-- In a well-fitted journal bearing with perfect lubrication the friction is determined by the speed, the pressure and the viscosity. Varying one of these with the other two constant, some value of the variable can be found which marks the limiting value of perfect lubrication, or the point where the film is partially destroyed. This is the point to be determined. In making these tests the temperature was at first considered incidental to the object of the experiment, so the speed was kept constant, and the pressure found for the breaking down point. Readings of the temperature were taken and as there was considerable variation of the same, the curves between speed and pressure were plotted for constant temperatures. In some tests on different oils by Mr. Albert Kingsbury as to temperature, there was a certain point (180 F), with the journal speed constant at 43 feet per minute, and a pressure of 340 pounds per square inch, at which the coefficient of friction was a minimum and on either side it varied greatly. This also shows that the temperature is one of the most important factors in experiments of this nature.

CHAPTER II.

General arrangement of apparatus:-- Fig. 1 shows the general assembly of the apparatus. The power was taken from a shaft in the laboratory, which ran at approximately 125 revolutions per minute. From the university shops was obtained a lathe headstock (A), and its corresponding countershaft with four cone pulleys. This countershaft was lagged to the floor under the main shaft and belted from it to the headstock as shown in Fig. 1. To the faceplate(B) of the headstock, by means of a dog and clamp is fastened a three foot shaft (C), on the other end of which a face plate (D) is driven. This faceplate is bolted to a corresponding face plate (E), on the shaft (F) of the journal. The testing apparatus itself (G) is placed on a 10000 pound Olsen test--ing machine (H), for the purpose of allowing any desired pressure on the bearing.

Testing apparatus:-- (See Figs. 2 and 3). This testing apparatus consists of the journal (I) and its bearing (JJ), the tin oil-box (K) around the same, the shaft (F) with a universal joint effect at either end, the outer bearing (L) the face plate (E) and the base (M). The bearing, consisting of a cast iron box (N) and phosphor bronze bushing (O), was first bored and then reamed. This bearing is split in the middle, giving a gap of 3/16". This is for the purpose

of allowing flooded lubrication. After the bearing had been completed, the journal was ground three thousandths of an inch (.003") smaller in diameter. The final dimensions of the journal bearing were -- length of box, three inches, diameter of journal 2.17893 inches. This grinding was done with such extreme care that in the final finishing the grinding wheel was run over the surface for twelve hours without changing the setting of the wheel. Due to the accurate workmanship a journal which was perfect within the limits of observation was produced.

Construction of journal:-- (See Fig. 4). The journal (I) is hollow throughout and of square cross section in the middle, as shown at V, figure 4. Into this square portion fits a corresponding square end (P) of the shaft connecting journal and outer bearing. The driving is accomplished at the center of the journal and as this is done by means of what is practically a line contact, we have in the journal a universal joint effect which makes up for any disallignment caused by the application of the pressure. In the journal running in the outer bearing a similar effect is obtained by means of the pin (Q); thus there are two universal joints in the testing machine proper.

Shaft connection from headstock to apparatus:-- (See Fig. 1) To the end of the shaft as it comes from the outer bear-

ing, the faceplate.(F) is secured by means of a driving fit. It was first intended to bolt this faceplate to that of the headstock (B) directly by means of four 1/2 by 2 1/2" machine bolts. Upon consideration, however, it was decided that the motion transferred so directly from the headstock to the apparatus would destroy the accuracy of the observations, so the idea of introducing a shaft between the two machines was carried out. After a shaft of proper length had been found, trued up, and driven into the faceplate (D), it was set up so as to give a sort of universal joint effect at each end. The faceplate on the shaft was recessed until it fitted easily over the faceplate of the testing apparatus. In the center of the shaft was bored a 1 1/2" by 1/4" hole into which was inserted a solid rubber plug. Faceplate (D) was then fitted over faceplate (E) and the two were brought together by means of four 1/2" by 2 1/2" machine bolts, which were tightened only with the fingers. To keep these bolts loose enough, four lock nuts were used. At the other end of the shaft (C) was set a dog. The center of the shaft rested on the headstock center, and was held in place by means of a clamp over the dog. Strips of rubber placed between this clamp and the dog took up any slight unevenness of motion between the two. The bolts used here were also tightened only with the fingers and here again four locknuts prevented the bolt nuts from be-

coming loose. By this arrangement two more universal joint effects were obtained in the shaft connecting the apparatus to the headstock.

Lining up:- Although these universal joints were designed and arranged with the view of compensation for any small amount that the apparatus might be out of line, still the fact that the first allignment was made as carefully as possible is attested by the time that it took to have the machines accurately set up. The countershaft and headstock were very easily lined with the pulleys of the main shaft by the usual methods of alligning shafting. Where the main difficulty came was in getting the center line of the headstock shaft and that of the shaft of the testing apparatus at the same height and on the same straight line. After the Riehle testing machine had been clamped down to 2" planks as shown in figure 1, the headstock center was raised by the insertion of washers and tin liners between the headstock and the frame upon which it rests.An engineer's "Y" level was used to determine when this was at the same height as the center of the shaft of the testing apparatus, while a spirit level held against the face plate of the headstock indicated when the center line of the headstock shaft was horizontal.

In lining up the apparatus horizontally a fine thread was stretched along the side of shaft (C) and directly above a

line marked on the floor parallel to the line along which the machines were to be set up. The headstock had previously been set over the original line. A plumb bob aided materially in lining up the headstock and in getting this thread directly over the line on the floor. The height of the thread was just that of the center line of shaft (C). Then by the usual means of measuring all the diameters on the headstock (shaft, pulleys, collars, etc.) and taking the distance from one of these collars to the thread as a standard, each point of the testing apparatus was lined up by setting inside calipers at a distance equal to the distance from the standard to the thread plus or minus the difference in radii between the two collars, according as the collar being drawn in line was smaller or larger than that taken as a standard, and seeing that the collar being lined up was just that distance from the thread.

This lining up was quite a tedious undertaking. Several times were the tests fairly started, only to necessitate again taking the apparatus apart and relining it. The smoothness with which the journal finally ran, however, was ample reward for the time spent in allignment. To further aid in enabling the machine to run evenly the center rest (R) was obtained from the lathe already resorted to, and set up around the shaft as shown in figure 1. With this center

rest in place the journal ran as smoothly as could be desired with the highest speeds used.

Speeds:-- It was at first intended to make the tests with speeds ranging from 50 to 1000 feet per minute corresponding with this journal, to revolutions of 100 to 2000 per minute. As the main shaft was speeded at 125 revolutions per minute, and the pulleys obtainable gave a maximum ratio of about 9:1, the highest speed that could be used was 1071 revolutions per minute or 611 feet of journal surface speed. As a matter of fact, at the two highest speeds tried, the power at hand was insufficient to run the machine at high pressure, so the higher speeds could not have been used in any case. With a maximum sized pulley on the countershaft 12" in diameter, it was figured that a 14" pulley on the main shaft would give a minimum journal speed (without using the back gears of the lathe) of 57.1 feet per minute. It was not necessary to use the back gears (except in the case of the cylinder oil, as explained later), as their use would have given speeds so low as to make the results found from them of no value. Eight different speeds were thus obtained ranging from 57.1 feet per minute to 1071 feet per minute. The speeds as computed for the 125 R. P. M. of the main shaft are as follows:

30" Pulley on 10" Pulley,

1. 1071 R. P. M. or 611 ft./min.

2. 638 R. P. M.or 364 ft./min.
3. 404 " " " or 231 ft./min.
4. 258 R. P. M. or 147.5 ft./min.

14" Pulley on 12" Pulley,

1. 333.5 R. P. M. or 190 ft./min.
2. 248 R. P. M. or 141.5 ft./min.
3. 157 R. P. M. or 89.5 ft./min.
4. 100 R. P. M. or 57.1 ft./min.

The speeds, as taken were necessarily not of these values, but varied slightly with the pressure. The speed was observed during the tests by means of a speed indicator held at (S) the end of the headstock shaft.

Electrical connections:-- The object of these tests as already stated was to determine the breaking down point of the film of oil between the journal and bearing. To find this exact point electrical methods were used. Running out from the shaft of the testing apparatus there is a small copper rod (T figures 2 and 3) with a copper disc (U) on the end. This disc ran during the experiment in a bath of mercury placed directly beneath it on the base of the machine. Into this bath is run one lead from each of two lamp socket plugs taking 110 volts A. C. from the lighting circuit. Soldered to the upper journal box is a wire running to voltmeter 1 (fig. 1)and then back to one of the lamp socket plugs, while to the lower journal box is fastened another wire running to

voltmeter 2 and thence to the other plug. Thus each voltmeter is connected in series with the shaft and one of the journal boxes. The oil between the journal and bearing acts as a non-conductor when the film is set up, and when either voltmeter registers 110 volts, or the normal value of the pressure, we know that there is metallic contact between the journal and bearing and that perfect lubrication is destroyed. The two voltmeters are for the purpose of discovering whether the film breaks down on the top or the bottom first. To prevent short circuiting the oil box and outer bearing are both insulated from the base of the apparatus by means of fiber strips and the bolts holding these parts down to the base are inserted in fiber collars and have fiber washers under their heads. At one time during the experiment the lower voltmeter continually read 110, indicating a short circuit. By a method of careful elimination this was traced to one of the bolts holding down the outer bearing, and was found to be due to some metallic filings around the head of the nut. After this had been remedied, great care was taken to prevent any further short circuiting as in each such case it was necessary to take the apparatus apart.

CHAPTER III.

Preparations and trial test:- After the machinery had been accurately lined up and the electrical connections properly adjusted preparations were made for a trial run on the first oil to be tested. First, the journal bearing and oil tank were carefully cleaned with filtered gasoline, after which the oil, also previously filtered to remove any sediment that it might have contained, was poured in to a height of about 3/4" above the shaft center. To exclude any particles of dust during the runs, a linen bag was placed over the tin oil tank, around which was also packed a thick felt jacket, for the purpose of preventing radiation of the heat. The thermometer for the measurement of this heat was inserted through an opening cut in the tank. This thermometer was held in different places in the tank during our tests and the results obtained established the fact that the temperature throughout the oil in the box was practically uniform due to the constant churning of the oil.

After every possible precaution had been taken the journal was started on the lowest speed and with about fifteen pounds to the square inch pressure on the bearing. The point of greatest interest here was the action of the voltmeters. It had been intended to use as incandescent lamp for the purpose of discovering when the film broke but the

manner in which the voltmeters registered showed very plainly that such a method would have been impossible. With this fifteen pounds per square inch on the bearing both voltmeters read 0, but as the pressure was gradually increased, both began to register, and the indicators rose rapidly up to about 95 and then very gradually up to 102 or 104 volts until at a pressure of 786 pounds per square inch, the lower voltmeter read 110, showing that the film was broken between the journal and the bottom box. At the instant the film broke in all of the tests, great care was taken to remove the pressure, to avoid abrasion of the rubbing surfaces through metallic contact.

After many trial tests to make sure that the machinery was in perfect running order, the oil in the tank was removed and the apparatus again carefully cleaned with filtered gasoline.

Method of making tests:-- The method of procedure in all of the tests was the same. After the oil had been filtered and poured into the tank, and the thermometer, linen bag and felt jacket put in place, the tests were always started with the lowest speed and practically no pressure. The pressure was then increased as quickly and smoothly as possible, in order not to interfere with the stability of the film until the pressure was so great that it broke. As soon as either voltmeter registered 110, the pressure was released,

the machine stopped, and the next speed taken up. Up to about 50 pounds per square inch pressure both voltmeters continually read 0 after which they rose rapidly to about 90, when the rise became very gradual until the film was broken. One fact worthy of note was that in all the authentic tests hereinafter given, the bottom film was the first to break. Whenever the top voltmeter registered 110 before the bottom one, upon repetition of the trial, in every case the lower film broke first. This formed an excellent check as to the general correctness of the results obtained each time.

It may be noted that when the journal was at rest the voltmeters registered 110 regardless of pressure.

Temperature readings were taken at the beginning and end of each run. It was impossible to obtain a constant temperature in running upon the speeds as the higher speeds with corresponding pressures necessary to break the film caused a marked rise in temperature. This was probably due as much to the leather packing on the outside of the tin oil tank as to the pressure on the bearing. In running from the highest speed to the lower ones, however, temperatures within five or six degrees of each other were obtained because the heat generated was just about enough to make up for the tendency for the temperature to fall due to radiation as the speed was decreased.

With each oil runs were made going up on all the speeds, taking two separate readings for each speed and releasing the pressure between each reading, then, down on all the speeds, again taking two readings each time. In this manner four breaking down points were obtained for each oil at each speed, giving a large range of temperatures.

Plotting and calibrating data:-- The data thus obtained, given on pp 22-24, was plotted with total pressures and pressures in pounds per square inch as ordinates and feet traveled per minute as abscissae, in the following manner: First all the points obtained for each oil were plotted separately. For each speed there were four points, generally two at a high pressure at practically the same temperature and a like two at a lower pressure. By averaging each two of these points(speaking for but one speed) and then noting the pressure distance between these averages and dividing this distance by the difference in temperature between the two sets of points, the change of pressure for one degree of temperature was very readily found. This method of calibrating the pressures for temperatures with each speed made possible the plotting of the speed pressure curves at constant temperatures as shown by curves on pp.

Purpose of curves:-- These curves show, therefore, the breaking down point of perfect lubrication for the oils tested, for varying speed and temperature but only for a

journal of the size used. At least there is at present no reason for supposing that the results here obtained would hold good for bearings of other sizes. It would be interesting to take up tests of this character with journals of different diameters to see what effect the size would have upon the results. It is certainly natural to presume that there would be some difference.

Films established by the different oils:- The order in which the oils were tested was as follows:

1. Renown Engine Oil.
2. Atlantic Red Engine Oil.
3. Vacuoline Engine Oil.
4. Cylinder Oil.

Of the first three of these oils the film established by Atlantic Red was the most difficult to break down. That set up by Vacuoline was more readily broken than the first, while Renown stood the least pressure of the three. This is shown very nicely by the curves. It may be readily seen that the curves for the Atlantic Red Engine Oil (taking same temperature in making comparison) are the steepest, while those for Vacuoline Engine Oil come next, with the curves for Renown rising more gradually than either of the others. To take a specific example, at 80 F and with a speed of 100 feet per minute the pressure required to break the film for each of

these oils was as follows:

Atlantic Red -- 8000 pounds total.

Vacuoline Engine -- 6800 pounds total.

Renown Engine -- 5350 pounds total.

The curves plotted from the results obtained are in general of a similar form. At first the pressure increases gradually with the speed, but soon a small change in speed is responsible for a great change in pressure, while on the higher speeds the pressure again changes more gradually with respect to the speed.

Behavior of cylinder oil:-- The cylinder oil seemed to be in a class by itself. With the speeds used in the case of the other oils it was impossible to break down the film established by the cylinder oil. With the lowest speed of 74.1 feet per minute the highest reading obtainable on either voltmeter up to the 10000 pound limit of the testing machine was 98 volts on the lower one. By means of the headstock back gears speeds down to 10.83 feet per minute were available and from this speed up to 22.8 feet per minute the film broke within the limit of the machine. On these very low speeds, however, the temperature did not rise materially, so only one temperature curve is plotted for this oil. It is quite probable, too, that this curve is of little value, owing to the extremely low speeds from which it was obtained. It

must be noted that for the sake of convenience, the curve for the cylinder oil is plotted to a scale different from that used in the case of the others.

Effect of viscosity:-- It is interesting to note how the results obtained from the viscosity tests of the oils, page 25, check up with their film building qualities. As may be seen from the results the order in which the oils stand to each other in regard to viscosity is as follows:--

Cylinder Oil, most viscous.
Atlantic Red, next.
Vacuoline, next.
Renown, least.

Thus it is found that the pressure required to break down the film established by an oil varies in some manner directly as the viscosity of the oil.

General conclusions:-- Throughout the experimenting the values of pressures obtained undoubtedly exceeded by at least 600 or 700 percent the pressures that an ordinary bearing would have been expected to stand, and in the case of the cylinder oil, there is no knowing what pressure might have been required to break down the film at higher speeds. It must be realized, however, that the bearing here used was of extreme excellence. These results show therefore the advantage and importance of having journals and bearings of the finest workmanship wherever possible. It would undoubtedly bring

forth some most interesting results to make a series of tests of this same nature on an ordinary commercial bearing and to compare the data obtained with the results from the experiments here described. If a relation could be found between the pressures that would be borne by bearing of different sizes under the conditions of perfect lubrication, a table could be made which would be of great value to everyone interested in this work. Within limits the apparatus here described could be used for the testing of different journals, by merely making the journals and bearings of desired size and inserting them in the tin tank without changing any other parts of the machine.

Another change which might be made in future tests on this work would be to allow the apparatus to run for some time (say 24 hours) under the same conditions of speed and pressure. In these experiments, it will have been noted, the pressure was being changed continually and the speed was changed each time the film broke. It might be that running for a long time under constant conditions would introduce temperature changes that would materially affect the results.

The oils used in these tests were kindly furnished by Mr. R. G. Collins, Manager of the Milwaukee branch of the Standard Oil Company.

In the preparation of this thesis much aid was obtained from the articles of Prof. R. H. Thruston, Prof. Albert Kingsbury and of Mr. Moore of the University of Wisconsin. The work of Mr. Moore is more in the line of that discussed here than any other heretofore accomplished. His articles are to be found in the American Machinist for 1905.

Renown Engine Oil.

Speed		Pressure at breaking of film	Temperature
rev.	ft. per min.		
130	74.1	4700	69
130	74.1	4640	68.6
200	114	6870	72
200	114	6670	74
302	172.1	8730	79
302	172.1	8730	79
510	290.7	9950	89.4
510	290.7	9370	94
516	294.7	5860	115.2
516	294.7	5880	115
302	172.1	3800	116
302	172.1	3840	116
200	114	2140	115
200	114	2150	115
130	74.1	920	114
130	74.1	940	138.

Atlantic Red Engine Oil.

rev.	Speed ft. per min.	Pressure at breaking of film	Temperature
130	74.1	5450	87
130	74.1	5400	87.5
202	115.1	7450	91
202	115.1	7440	91.1
300	171	8720	98.9
300	171	8680	99.1
514	293	8610	115.5
514	293	8600	115.5
312	177.3	5920	116.5
318	181.3	5880	117
200	114	3950	117
200	114	3860	117
130	74.1	2150	116.5
130	74.1	2200	115.3

Vacuoline Engine Oil.

rev.	Speed ft. per min.	Pressure at breaking of film	Temperature
130	74.1	5370	78.5
130	74.1	4450	80
205	116.8	7350	82
205	116.8	6950	84
320	182.4	8940	87
320	182.4	8630	90
530	302.2	9930	99.2
530	302.2	9470	104.5
520	296.4	6150	133
520	296.4	6150	132
320	182.4	3960	132
320	182.4	3960	132
205	116.8	2440	130.5
205	116.8	2440	129.5
130	74.1	1080	128
130	74.1	1200	126

Cylinder Oil.

rev.	Speed ft. per min.	Pressure at breaking of film	Temperature
19	10.83	400	113
19	10.83	400	113
26	14.82	760	113.5
26	14.82	740	113.5
40	22.8	3650	113
40	22.8	3650	113
66	37.6	Did not quite break	113

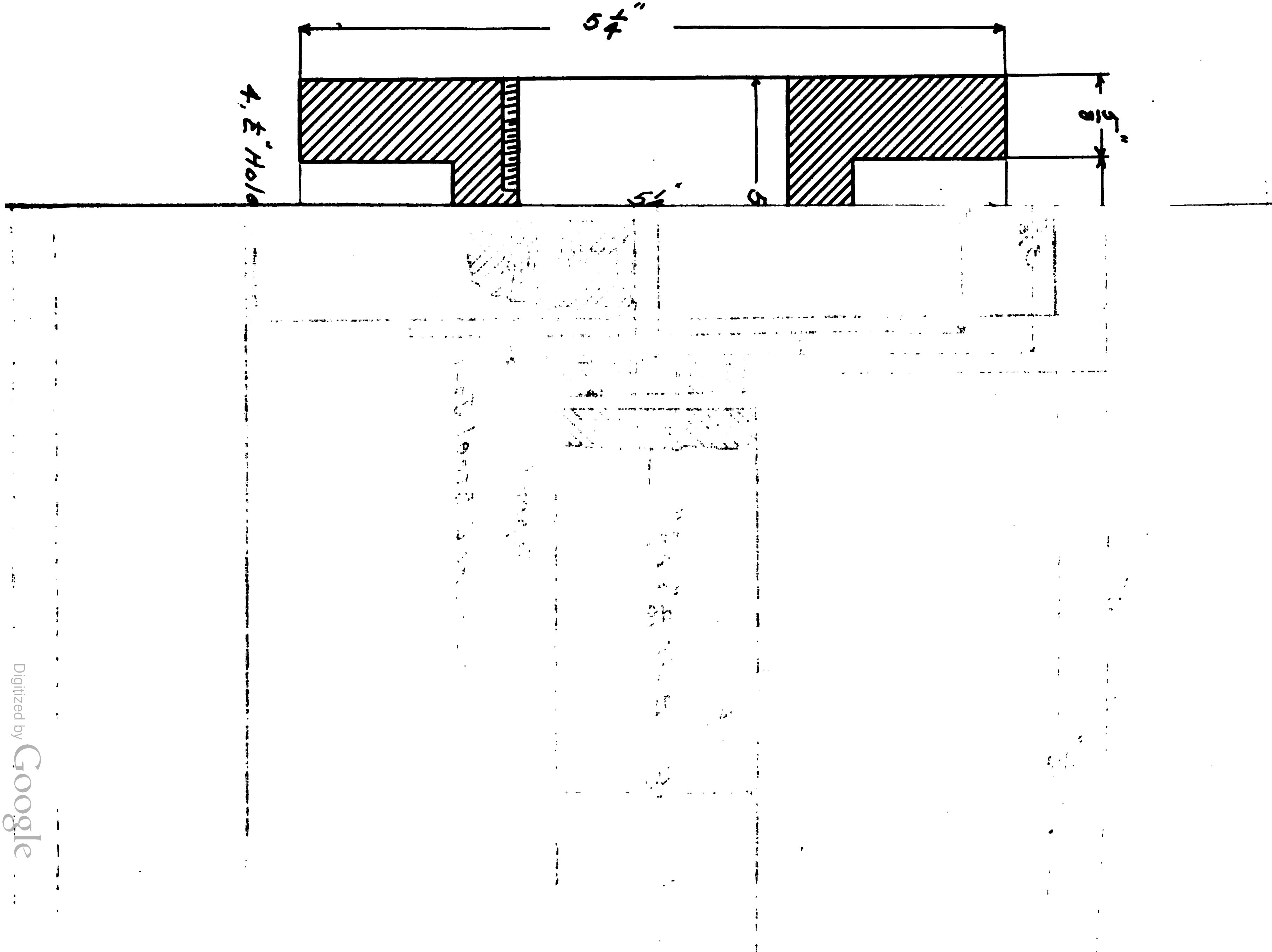
Viscosity Results.

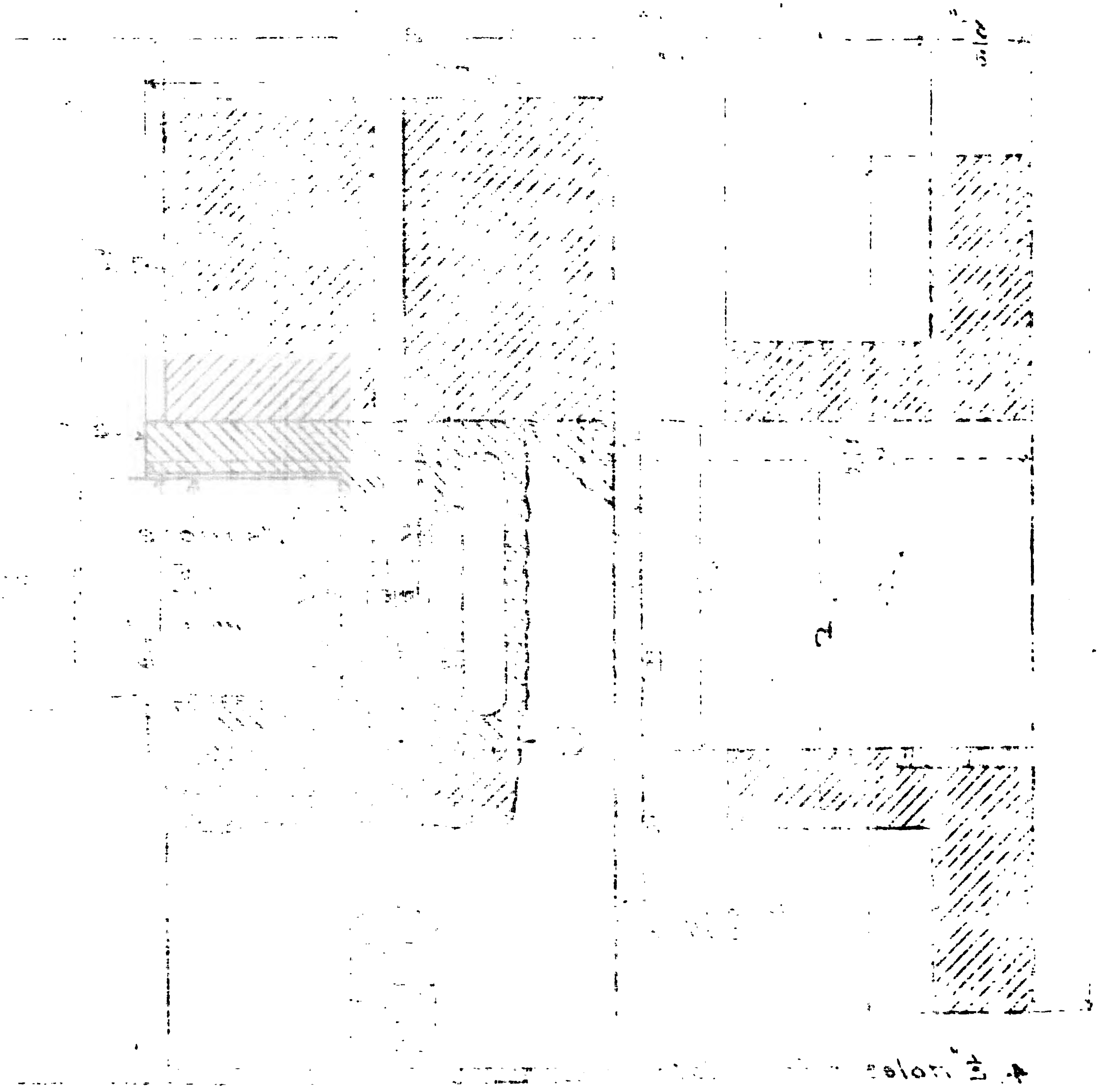
Fluid	Time for 100	Temperature
Water	28.2 sec.	
Renown Engine Oil	1 min. 50.6 sec.	80
"	57.6 sec.	113
	1 min. 15.6 sec.	100
	1 min 28.4 sec.	92
	45 sec.	131
Vascuoline Engine Oil	2 min. 28 sec.	82
	1 min. 48.6	91
	1 min. 30.2 sec.	100.5
	1 min. 18 sec.	109.5
	1 min. 4 sec.	120
	57 sec.	130
Atlantic Red Engine Oil	4 min. 27 sec.	71
	2 min. 59 sec.	80
	2 min. 14 sec.	91
	1 min. 46 sec.	100
	1 min. 20.5 sec.	110.2
	1 min. 10 sec.	120
	1 min.	130
Cylinder Oil	5 min. 20 sec.	128
	3 min. 52 sec.	142
	2 min. 55 sec.	152

A P P R O V E D

J G D Mack

Professor of Machine Design


5 1/4"
5/8"
5
5 1/2"
4, E" Hole



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